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SHAFT SINKING AT THE MORTON SALT CO. MINE AT GRAND SALINE, TEXAS[1]

By M. Taylor[2]

INTRODUCTION

This paper describes the sinking and lining of a 14 foot 6 inch finished diameter shaft down to and into the salt of a typical dome of the Gulf States region. The conditions and nature of the strata encountered divide the work into three distinct sections - that in (1) alluvial surface deposits, sunk through by open caisson methods, (2) water bearing rock, directly above the salt, and in (3) salt.

ACKNOWLEDGMENT

The writer wishes to acknowledge the cooperation of the sinking contractors, The Dravo Contracting Co. of Pittsburgh, Pa., through E. T. Gott, vice-president, in furnishing the data used in this paper.

GENERAL DISCUSSION

Grand Saline is located in Vanzandt County, Tex., about 65 miles east of Dallas. The town is served by the main line of the Texas & Pacific Railway and also by the Texas Short Line Railway. A spur track from the former line connected with the mine over a distance of approximately 1 mile, construction being completed shortly after the shaft-sinking operations were commenced. This spur transported all construction materials for this job, and when the mine was in operation became the connecting link to the main line of the T. & P. Ry. for rail shipments of salt. The contract was carried out for the Morton Salt Co. of Chicago, Ill., who for a number of years have operated a brine pumping and evaporating plant on this same dome within a mile of this new development.

GEOLOGY

Before letting the contract, the owner drilled a number of core holes to determine the extent of this deposit and the nature of the overburden. These showed that the salt was in the form of a truncated cone having a diameter of approximately 1 mile, with its top practically level and under 210 feet of cover. The sides of the dome were found to slope off at between 50° and 80° from the horizontal, and as the deepest prospecting holes continued in pure salt to 900 feet, there is evidently enough salt in this deposit to supply a mining operation for an almost unlimited number of years.

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[1] - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6640."

[2] - One of the consulting engineers, U. S. Bureau of Mines, and engineer, Dravo Contracting Co.

The surface deposits, of Tertiary age (lower Eocene), consist of layers of sand, clay, and shale tapering into a soft sandstone which extends to the 190-foot level. Below this is a cavernous limestone containing salt water, and the 5 feet directly above the salt is a layer of anhydrite, also honey-combed and containing water-filled cavities of large extent.

In the soft sandstone measures above the dome, the entire stratification is horizontal, but on the sides, after the first 50 feet of sand and clay which is still horizontal, the strata pitch steeply, following the line of the salt. The inference is that the strata were folded by the salt intrusion, the top eroded away, and in the ages following covered by fresh alluvial deposits. Figure 1 shows the strata encountered and also a columnar section of the shaft lining.

PREPARATION AND PLANT

The initial plant set-up centered around a stiff-legged derrick with a 45-foot boom which was used for hoisting in the hole and also for handling materials at the surface. Concrete aggregates arriving by car were unloaded by clamshell into elevated bins. From these the materials passed through measuring boxes to the 3/4-yard concrete mixer, from which by means of a 60-foot tower, the concrete was transferred through chutes to the caisson forms. When lining below the caisson, concrete was lowered in a 3/4-yard shaft bucket.

The first 28 feet of caisson section was excavated by clamshell bucket. Below this depth, mucking was carried out by hand-loading into the shaft bucket. At the surface the muck was dumped into 1½-yard side-dump cars operating on a 36-inch gage track, which extended to the dump.

Two 60-inch diameter vertical boilers burning lignite coal furnished steam for operating the derrick and the cementation pumps during the grouting period. Two electrically driven 12 by 10 inch compressors, each of 325 cubic foot capacity, supplied air for drilling, drill sharpener, and pumping.

After reaching the salt a temporary steel headframe was erected, and a 100-hp. electric hoist put in operation. Thereafter the derrick was maintained for concreting only. About this time an electric fan and ventube were also installed for shaft ventilation. Salt was loaded into railroad cars for disposal by the salt company.

SHAFT SINKING

After leveling-off the surface and erecting the steel caisson shoe, the concrete wall 4 feet thick was poured inside steel forms. Figure 2 shows the caisson shoe and reinforcing steel. These sections were 8 feet deep, so that the concrete was added in lifts of that amount as sinking proceeded. Good progress was maintained down to 53 feet 9 inches, which depth was reached four weeks after erecting the shoe. At this point, water encountered about 15 feet above cut through under the shoe, causing a cave-in on the north side which threw the caisson 5 inches out of plumb. Blocking on the low side of the shoe and the use of kickers at the surface was then resorted to, but despite this the shell continued to move out, being 15 inches out of plumb at 64 feet. The ground was then excavated outside the caisson on the high side to a depth of 30 feet and the timber kickers reset on the opposite side. By careful manipulation and by jetting with air and water through pipes embedded in the caisson walls for this purpose, the shell was brought back to within 3½ inches of plumb at 82 feet.

Below this depth there was considerable difficulty in getting any movement with the kickers in position. However, by undercutting the shoe, jetting, and loading with an extra form filled with muck, the caisson was finally landed in shale 8 inches out of plumb at a depth of 107.25 feet and was sealed. As the inside diameter of the caisson had been made

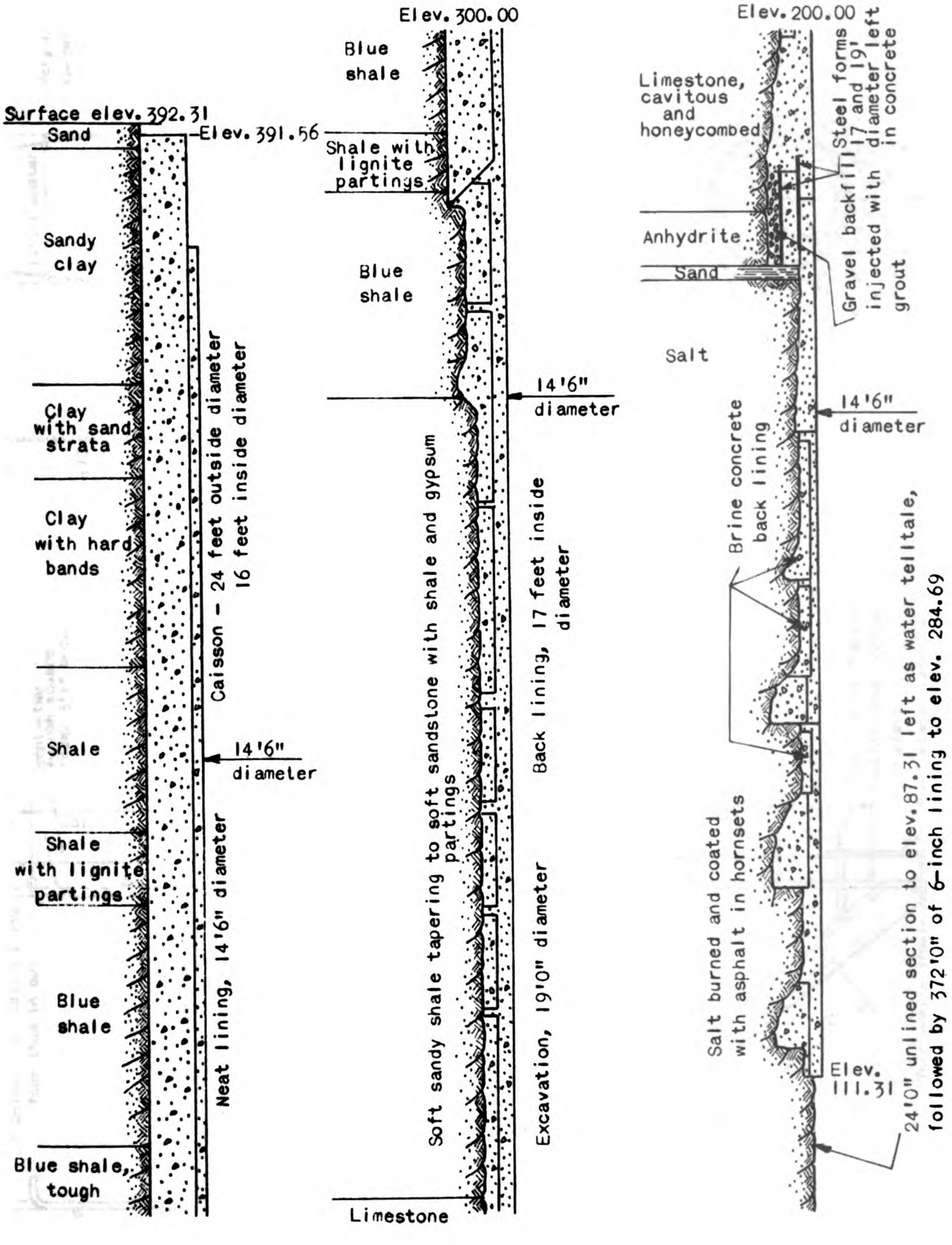

Surface elev. 392.31
Sand
-Elev. 391.56
Sandy clay
Clay with sand strata
Clay with hard bands
Shale
Shale with lignite partings
Blue shale
Blue shale, tough
Caisson - 24 feet outside diameter 16 feet inside diameter
14'6" diameter
Neat lining, 14'6" diameter
Elev. 300.00
Blue shale
Shale with lignite partings
Blue shale
14'6" diameter
Soft sandy shale tapering to soft sandstone with shale and gypsum partings
Back lining, 17 feet inside diameter
Excavation, 19'0" diameter
Limestone
Elev. 200.00
Limestone, cavitous and honeycombed
Steel forms 17 and 19' diameter left in concrete
Gravel backfill injected with grout
Anhydrite
Sand
Salt
14'6" diameter
Brine concrete back lining
Salt burned and coated with asphalt in hornsets
Elev. 111.31
24'0" unlined section to elev. 87.31 left as water telltale, followed by 372'0" of 6-inch lining to elev. 284.69

Figure 1.- Columnar section of concrete shaft lining showing strata encountered

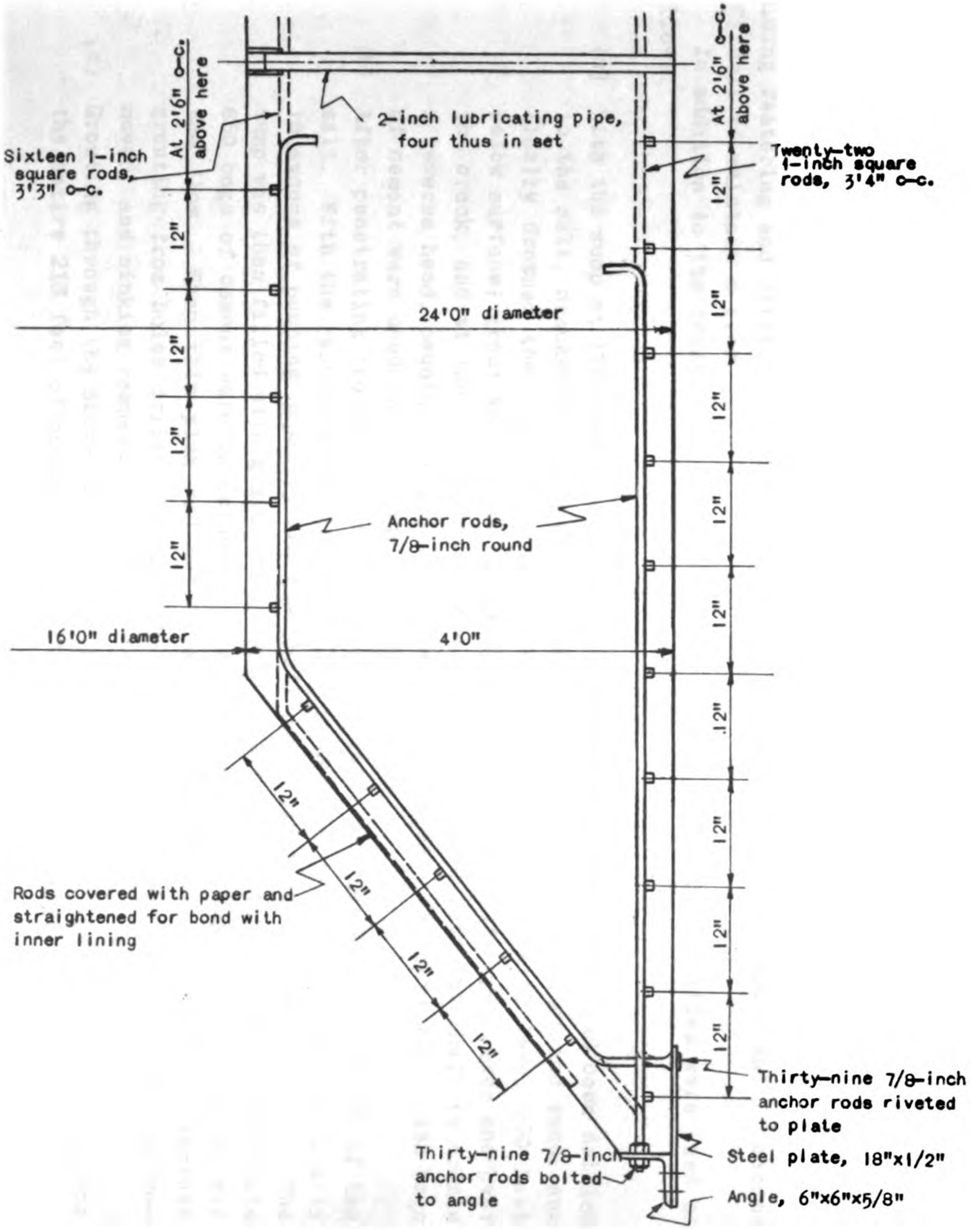
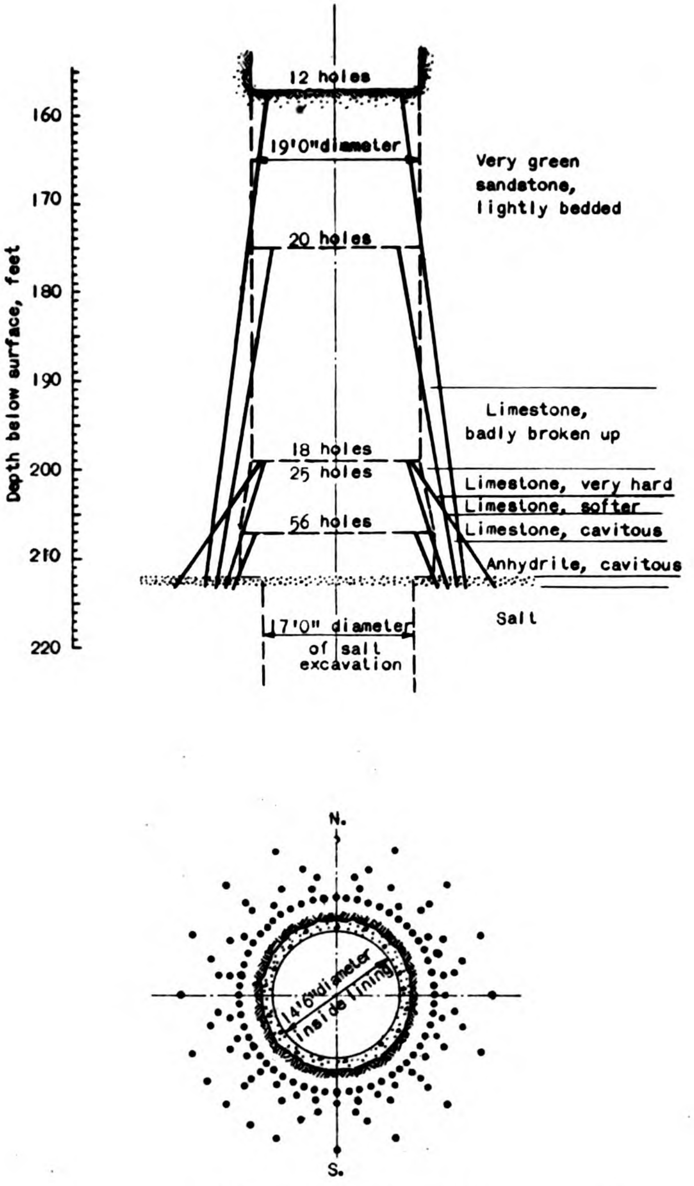

2-inch lubricating pipe, four thus in set
Sixteen 1-inch square rods, 3'3" o-c.
At 2'6" o-c. above here
At 2'6" o-c. above here
Twenty-two 1-inch square rods, 3'4" o-c.
12"
24'0" diameter
Anchor rods, 7/8-inch round
16'0" diameter
4'0"
Rods covered with paper and straightened for bond with inner lining
Thirty-nine 7/8-inch anchor rods riveted to plate
Thirty-nine 7/8-inch anchor rods bolted to angle
Steel plate, 18"x1/2"
Angle, 6"x6"x5/8"

Figure 2.- Caisson shoe and reinforcing steel



Plan of grout holes at sand

Figure 3.- Holes for cementation of water-bearing cap rock and sand

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16 feet, or 18 inches larger than the finished shaft diameter, the caisson as landed was well within the given allowance. These irregularities were later covered up by a 9 inch inner lining throughout the entire caisson section. Sinking then continued through blue shale, gradually passing into a soft sandy shale, and finally to a soft sandstone. At a depth of 157 feet 6 inches, the rock had hardened considerably and was considered strong enough to withstand grouting pressures. Consequently, grout holes were commenced from this level to penetrate the water-bearing strata below and were finally extended down to the salt at 213 feet, a total grouting length of 55 feet 6 inches. Figure 3 shows the holes for cementation of water-bearing cap rock and sand. The limestone and anhydrite cap rock were found to be very open, taking large volumes of cement; but the work went forward normally until the holes were drilled into the salt, when enormous amounts of water and fine sand under a pressure of 70 pounds per square inch came up the holes from the joint between the salt and anhydrite. Since the sand in this joint, which had an average thickness of 12 inches, could not be impregnated with grout, it was necessary to remove it on a sufficiently wide area to permit the joint to be thoroughly and completely filled with grout. To effect this, the cock on the stand-pipe was opened and the sand allowed to wash out of a hole, after which grout could be pumped in. In the later stages it was necessary to pump and spring the holes with dynamite to aid the movement of the sand before grout could be introduced. In all, five sets of grout holes from successive levels and each penetrating the sand on different diameters were projected to the salt, making a total of 131 grout holes with a total footage of 2,711 feet. Including the grout used in the rock injections, the cement consumption amounted to 8,429 bags. As stated above, the different circles of holes were drilled with the shaft bottom at successive levels, and consequently the short lengths of ground taken out between each grouting operation prevented systematic sinking which resulted in a high cost for this item. This was further aggravated by the action of the salt water on the skin of the men in the hole, causing festering and ultimately boils. Much time was lost on this account, and it became difficult to maintain a crew.

In addition to the cement used in down-hole grouting, further quantities were used as follows:

(a) With the sump at 175 feet, the pressure developed in a hole which had been drilled to the salt, cracked the weak sump, admitting huge volumes of water and sand, and finally drowned the shaft. After allowing it to fill to static level (50 feet below surface) grout was pumped down a pipe line which had its open lower end over the crack, and at the same time surface water was pumped into the shaft to create a reverse head, causing the grout to flow into the break. In this way, 1,163 bags of cement were used in effecting this seal.

(b) After penetrating the salt a small trickle of water was noticed at the top of the salt. With the resulting erosion, the flow quickly increased to an amount greatly in excess of pumping capacity and the shaft again had to be allowed to fill. The sump was then filled with gravel to a depth of 6 feet. Into this coarse aggregate 650 bags of cement were injected to form an underwater plug, which would cut off the flow. When this plug had set, the shaft was dewatered, and after further grouting from holes drilled through the plug, the leak was sealed, the plug removed, and sinking resumed.

(c) Grouting through the above plug and the final treatment of the concrete lining for the entire 213 feet of depth to the salt, consumed 1,094 bags of cement.

Drilling and Blasting

Holes were drilled by jackhammers, using cross bits dressed from 7/8 inch hollow-hexagon drill steel. In the rock section, owing to the varying nature of the formations passed through and the necessity of accommodating sinking to the grouting requirements, there was no set program for the round. Forty per cent gelatin with 1¼ by 8 inch sticks was used until the salt was entered, when, after many tests, a change was made to 30 per cent gelatin. The typical round in the salt was as shown in Figure 4. Data on drilling in salt is given in the following table:

Drilling practice in salt, using 1 by 8 inch dynamite, 264 sticks per 100 pounds

Holes	Number of holes	Depth drilled, feet	Linear feet drilled	Exploders		Dynamite, 30 per cent		
				Number used	Type	Per hole	Sticks	Pounds
Busters..........	3	4	12	3	Angular	3	9	3.4
Sump................	8	9	72	8	do.	9	72	27.3
Relievers......	15	8	120	15	do.	7	105	39.8
Line or rib....	22	7	154	22	First delay	7	154	58.3
Reshooting......	-	-	-	3	Regular	-	9	3.4
Total...........	48	-	358	51	-	-	349	132.2

Average round: 5.46 feet at 7.81 = 42.64 cubic yards (including overbreak).
Drilling per cubic yard of salt: 8.4 feet.
Drilling per pound of dynamite: 2.71 feet.
Pounds of dynamite used per cubic yard in salt: 3.10 pounds.
Number of exploders used per pound of dynamite: 0.38.

Using electric blasting caps fired from the surface, the sump round was shot out first; then while the muckers handled the broken material, the drillers continued working on the relief and line holes. Two men handled the drilling and four men the mucking. The relief and line holes were shot together by the use of regular exploders for the relief holes and first delays for the line holes. Here again drilling was carried out with cross bits and jackhammers after making trials with rotary auger drilling. While the auger cut faster than the cross bit, it was found that as the auger hole approached its full depth, the cuttings would not clear from the vertical hole, with the result that the hammer drill was given the preference.

Mucking

Below the first 28 feet of caisson excavation, which was handled by clamshell bucket, all mucking was done by hand-loading into 3/4-yard shaft buckets. In the salt where two 10-hour shifts per day were worked, each shift usually completed a round of drilling, shooting, and mucking, with the round averaging about 5½ feet and containing 43 cubic yards of material.

Pumping

While water in the rock and sand constituted the major problem, it was handled by grouting ahead of the sinking, so that apart from the breaks previously mentioned, no large flow of water entered the shaft at any time. A No. 8 Cameron pump was employed in the shaft when passing through the water-bearing ground, and handled the water by intermittent pumping. After installing the lining and grouting behind it, there remained only local damp places.

Sinking Performance

	Caisson section, 0 to 115 feet	Rock section, 115 feet to 226 1/3 feet	Salt section, 226 1/3 feet to 677 feet
Time worked, total............hours	808	714	938.5
Miners and bosses, total..........man-hours	6,028	4,763	6,816
Rounds, completed..................	-	26	83
Progress per round..............feet	-	4.28	5.46
Holes per round..................	-	26	48
Drilling:			
Time.................man-hours	-	799	2,266
Per man-hour..................feet	-	5.09	13.25
Per foot of advance..............do.	-	36.53	66.62
Blasting and blowing...........man-hours	-	504	1,073
Explosives per foot of advance........pounds	-	11.36	24.21
Mucking.....................man-hours	3,316	3,460	3,480
Excavation, effective.............cubic yards	1,896.4	1,304.73	3,282
Per vertical foot..................do.........	16.5	11.72	7.28
Per bucket......................do........	-	.638	.572
Per man-hour of mucking time......do.........	.572	.377	.943

LINING

As excavation proceeded in the soft rock below the caisson, short lengths of concrete lining were installed as shown in Figure 1. After reaching the salt, the lining to neat shaft diameter was installed through the rock section and continued up inside the caisson (fig. 5). The lining in the upper part of the salt was installed with a view to preventing any future possibility of water eroding the salt, thus creating a channel behind the lining. As shown, these precautions included the use of concrete mixed with a brine solution and the placing of three asphalt seals. Timber forms 6 feet deep with 4 segments to the circle were used for all the 14-foot 6-inch finished diameter lining, these being made and kept in repair on the job.

Concreting Performance

	Caisson and seal	Backwall, 115 to 212 feet	Neat lining, 10 feet 3 inches to 226 feet 4 inches in depth	Brine back lining in salt	Neat lining in salt
Handling forms...............man-hours	2,508	784	2,201	258	3,152
Placing reinforcing..............do......	513	-	268	-	374.5
Concrete:					
Mixing and placing..............do.......	1,305	707	1,012	127.5	1,322
Poured.......................cubic yards	1,025.2	290.5	472.35	59.1	707.25
Per foot of lining..............do.........	8.933	3.58	2.19	2.61	1.66
Total depth.....................feet	114.75	81.08	216.08	22.66	426.66

Grouting Data

	Hours	Man-hours	Number of units	Units per man-hour
Down-hole grouting:				
Plant erection, repairs, etc.	66	724	-	-
Drilling:				
For 2-inch ground pipes, and placing pipes	357	2,059	1,027 feet	0.401 feet
1 7/8-inch holes	440.5	2,696	1,684 feet	.625 feet
Injecting:				
Cement	344	2,011	8,429 sacks	4.19 sacks
Chemicals	44	259	189.5 cwts.	.73 cwt.
Cleaning out holes (cement drilling)	489.5	3,042	9,877 feet	3.25 feet
Springing and blowing sand from holes	96	544	1,152 cu.ft.	2.12 cu.ft.
Other grouting:				
Sump failure at 175-foot depth	158	554	1,163 sacks	-
Under-water plug, 210 to 216 feet	25	158	650 do.	-
Behind backwall, 203 to 212 feet	8	44	321 do.	-
Behind lining	159	1,815	773 do.	-

Grouting, total hours	2,187
Grouting, total man-hours	13,906
Cement injected, total sacks	11,336

SHAFT EQUIPMENT

As Figure 5 shows, the shaft was arranged to provide an air compartment and two hoisting compartments. The bunton support castings were placed at 6 feet, vertical spacing, by attachment to the shaft forms before concreting. Therefore the time spent on these is included under concreting, in the item "Handling Forms."

	Man-hours			
	Framing	Placing	Total	Per vertical foot
Guides, 749 vertical feet	790	1,218	2,008	2.68
Buntons, 739 do.	163	1,303	1,466	1.98
Brattice, 677 do.	-	1,526	1,526	2.25

COST OF SINKING AND LINING

The following tables give the cost of sinking and lining in dollars and in man-hours for the different sections, but do not include the cost of grouting, the installation of shaft equipment, and the shaft-bottom work which carried the opening to a total depth of 739 feet from the surface; nor do they include the three asphalt seals in the salt, and the complete construction of the hornsets as shown on Figure 1. Table 1 gives the cost in dollars per foot of shaft for the three sections and Table 2 the costs in man-hours of labor.

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Table 1 - Cost per vertical foot

	Caisson and seal. 0 to 115 feet				Rock section. 115 to 226.33 feet				Salt section. 226.33 to 677 feet			
	Direct labor	Permanent material	Construction material and indirect labor	Total	Direct labor	Permanent material	Construction material and indirect labor	Total	Direct labor	Permanent material	Construction material and indirect labor	Total
Drilling and blasting	-	-	-	-	$8.19	-	-	-	$5.00	-	-	-
Drills, repairs, steel, air and water lines	-	-	-	-	-	-	$10.30	-	-	-	$2.15	-
Explosives	-	-	$0.81	-	-	-	3.39	-	-	-	5.97	-
Mucking	$15.11	-	-	-	16.99	-	-	-	4.25	-	-	-
Disposal of muck	9.46	-	-	-	10.40	-	-	-	3.32	-	-	-
Plumbing caisson	12.39	-	.95	-	-	-	-	-	-	-	-	-
Operative labor to sinking	-	-	9.62	$48.34	-	-	12.46	$61.73	-	-	3.37	$24.06
Caisson shoe steel	.47	$4.90	-	-	-	-	-	-	-	-	-	-
Permanent material, misc	.22	1.78	-	-	-	-	-	-	-	-	-	-
Reinforcing	1.95	8.38	-	-	2.18	$5.14	-	-	.63	$0.86	-	-
Panning water	-	-	-	-	1.59	.63	-	-	.45	.07		
Concrete forms, handling	11.83	4.12	6.93	-	10.73	2.09	5.24	-	3.68	-	2.63	-
Concrete mixing and placing	6.68	71.52	-	-	6.98	36.68	-	-	1.94	12.93	-	-
Operative labor to concreting	-	-	4.69	123.47	-	-	7.05	78.31	-	-	1.88	25.07
Pumping	-	-	.96	.96	-	-	5.35	5.35	-	-	-	-
Ventilation	-	-	-	-	-	-	-	-	-	-	1.11	1.11
Power	-	-	6.83	6.83	-	-	10.83	10.83	-	-	2.95	2.95
Construction material, misc	-	-	7.82	7.82	-	-	7.72	7.72	-	-	2.28	2.28
Indirect labor, misc.	-	-	10.26	10.26	-	-	5.72	5.72	-	-	3.01	3.01
Supervision (local office)	-	-	14.46	14.46	-	-	13.59	13.59	-	-	3.69	3.69
Totals	58.11	90.70	63.33	212.14	57.06	44.54	81.65	183.25	19.27	13.86	29.04	62.17

Note: The hoisting engineers time is allocated to the various direct labor items.

TABLE 2.- Labor expended, man-hours

	Caisson & seal		Rock section		Salt section	
	Total	Per foot	Total	Per foot	Total	Per foot
Drilling and blasting	-	-	1,803	11.70	3,339	7.41
Mucking	3,316	28.84	3,460	31.08	3,480	7.72
Disposal	1,857	16.15	1,575	14.15	1,983	4.40
Plumbing caisson	2,712	23.58	-	-	-	-
Concreting	5,733	50.18	3,565	32.02	5,234	12.26
Hoisting	1,264	11.00	1,058	9.50	1,359	3.02
Operative and indirect labor	5,958	51.81	6,342	56.97	7,706	17.10
Totals	20,840	181.56	17,303	155.42	23,101	51.91

	Caisson section	Rock section	Salt section
Vertical feet of shaft per man-shift:	Per 10-hour shift, 0.055;	per 8-hour shift, 0.051;	per 10-hour shift, 0.193.
Average pay per shift:	$4.80	$4.56	$5.46

	Caisson section	Rock section	Salt section
Time worked in shaft........days	79	55	86
Progress:			
Total........feet	115	111.33	450.66
Sinking and lining, per day..do.	1.455	2.02	5.24

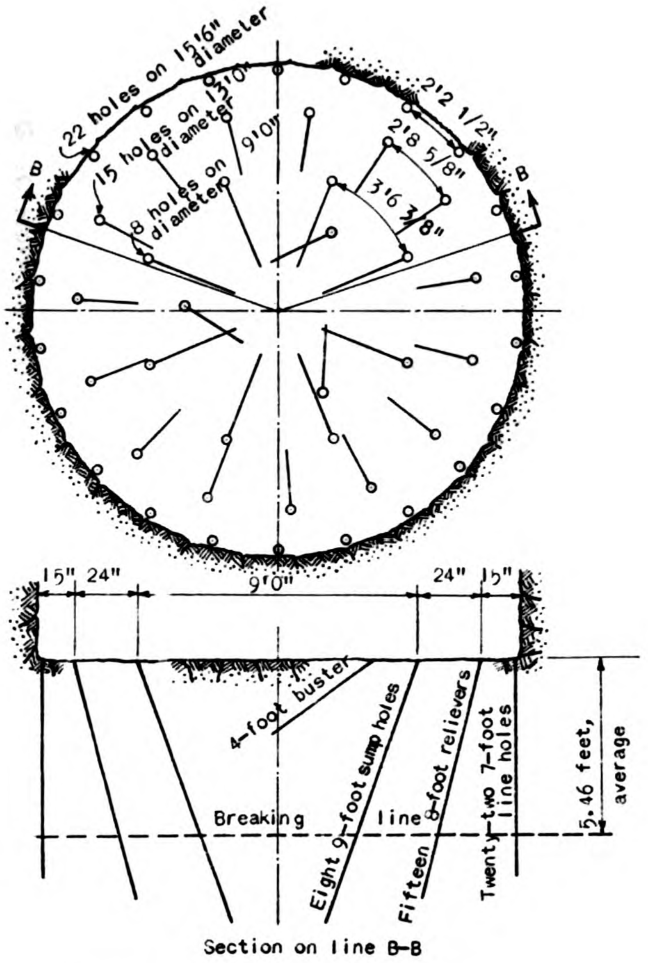

Figure 4.- Drilling diagram in the salt

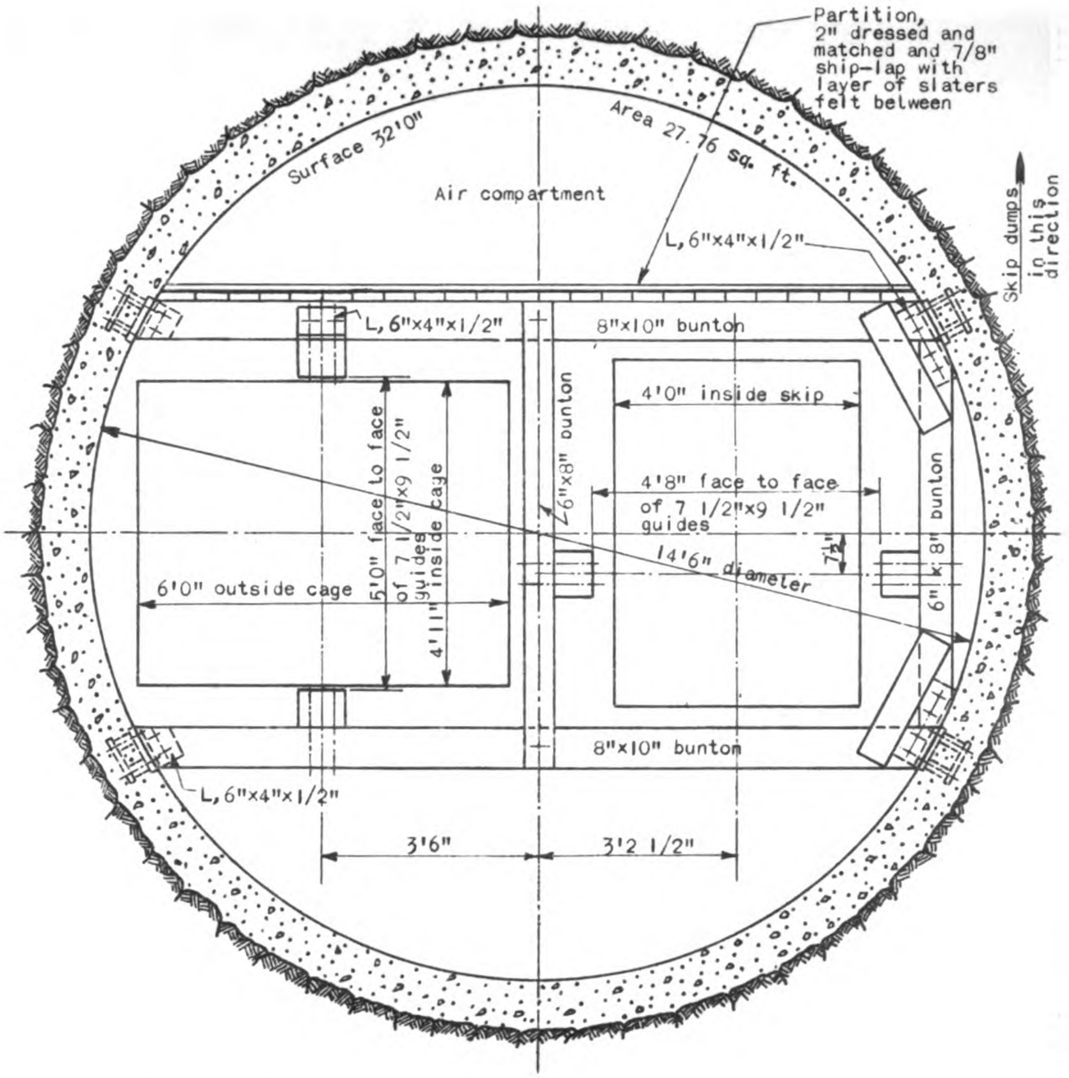

Figure 5.- Typical section of shaft in salt, showing location of guides and skip

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